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An Adaptive Cognitive Temporal-Causal Network Model of a Mindfulness Therapy Based on Music

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Abstract. In this paper the effect of a music therapy is modeled based on a Network-Oriented Modeling approach. Music therapy is a mindfulness therapy used since many years ago. The presented adaptive temporal-causal network model addresses music therapy for a person who in a first phase develops an extreme stressful emotion due to an ongoing stressful event. In a second phase, music therapy is considered to reduce the stress. This happens by playing memorable music first and then singing on that music. The music and the singing have a direct relaxing effect on the body. Hebbian learning is incorporated to increase the effect of the therapy.

Keywords: Cognitive temporal-causal network model · Hebbian learning Extreme emotion · Music therapy · Mindfulness

1 Introduction

Mindfulness therapies help on decreasing the level of an extreme emotion to make stressed-individual gets relaxed and became calm after some period of time after performing available therapies related to decrease the stress level [29]. Some of these therapies are currently approved to be work perfectly therapies like Music therapy and Autogenic training [30] which have started as a therapy many years ago and have been proved to have a good effect by decreasing the level of the emotion and some of them are still under investigation named Gene therapy which works with putting enzyme into the cells by using viruses as a vector. A variety of therapies working according to different mechanisms, is available, some of which have been analyzed by computational modeling; for example, see [30–33]. In [30] the two main goals in Autogenic training have been taken into account, focusing on warm and heavy limbs; the cognitive model shows how this therapy achieves reduction in the person's stress level, thereby using Hebbian learning. In [18] it is stated that music therapy uses musical interaction as a means of communication and expression. Due to the fact that lyrics demonstrate melodic verbal communication, there is an innate association between songs and relationship between different humans [2]. In [2] the elements of music therapy are stated as:

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'Elements of song experiences -cognitive stimulation, the building of relationships, singing, and listening- can provide frameworks for tension release, integration, and pleasure. (…)
Music therapy in the care of cancer patients and their families aims to promote comfort, develop meaningful communication, and resolve issues. The music therapist aims to soothe and energize, stimulate the expression of thoughts and feelings, help integrate families and persons into their social environments, provide sensory stimulation, and diminish pain.' [2], pp. 5–6.

Complicated Grief (CG) is a condition of ongoing firmly or obstinately in a course of action in spite of difficulty or opposition of symptoms of sorrow, which in the model introduced here is the image of a lost person considered in the mind of the person to remember the lost one for the sad music, with the thoughts of the lost person [24].

The paper is organized as follows. In Sect. 2 the neuropsychological principles of the effects of stress and the parts of the brain which deal with stress are addressed. In Sect. 3 the adaptive temporal-causal network model is introduced and illustrated by simulation of an example scenario. In Sect. 4 the simulation results of the model are discussed. Finally, Sect. 5 is a discussion.

2 Neuropsychological Principles

In [17] it was found out that music has an impact on Prefrontal cortex and also high tempo music (but not low-tempo music or low-level noise), has a considerable impact on learning and performing suppressing control. Also, in contrast to visual stimuli, they figured out that music itself has an impact on the cognitive functions: 'In contrast to images, high tempo music appeared as a salient cognitive factor that significantly attenuated learning to inhibit the inappropriate response.' In this section the neurological principles of music therapy in different areas of brains will be explained.

First the Amygdala is considered [1, 4, 10, 11] to perform an action while listening to the music. During listening to joyful music, the connectivity is increased between Nucleus Accumbens (NAcc), and between the mediodorsal thalamus and amygdala. The laterobasal amygdala which consists of the lateral, basolateral, basomedial, and paralaminar nuclei, is responsible for auditory and sensory perception and information. The amygdala is responsible for beginning, integrating, preserving and canceling emotions. In [12] results on music stimuli emotions are presented in a sense that music influences the performance of emotion processing in brain areas like Amygdala, Hippocampus, Orbitofrontal Cortex. As noted in [14] there are two types of regulation that need to be adjusted in mourning and grief: External adjustment, Internal Adjustment.

The External adjustment begins with singing of the individual who has lost somebody (deceased person) in her life and the difficulties that she has in her life without her. 'Participants sang imaginal songs with their deceased loved ones about their problems, especially if the deceased had been a person who provided deliberations and support in the individual's life. Individuals verbally acknowledged adjusting to the external world, such as sensing closer to surviving relatives since the death.' [14]. In the External adjustment individuals think about how they have improved their feeling as it has been explained in [14], p. 179.

'Data showed that all the participants reflected on their personal strength. For example, "I feel alive, actually. A sense of growth. Growing. I am stronger than I look'.

The remarkable aspect of hearing music is that it can adjust and incite perception and cognition [7]. In much literature [7, 20, 25] it has been noted that music, with using perceptual patterns, under-takes attentional networks and it was shown that music makes changes in EEG topography and coherence in alpha brain wave rhythms among frontal cortical networks. In [9] it was demonstrated that music can reduce stress and anxiety:

'music offers a comfortable, nonthreatening milieu which is an important aspect for the mood of the patient during therapy sessions.' [9], p. 11.

In [16] the emotional results have been stated as follows:

'Emotions give rise to affective experiences such as feelings of happiness, sadness, pleasure, and displeasure; activate widespread physiological adjustments to the evoking conditions; and lead to expressive behaviors that are often, but not always, goal directed and adaptive.' [16], p. 62.

There are many ways how music can stimulate emotions as brain stem responses, evaluative conditioning, emotional contagion, mental imagery, episodic memory and musical expectancy [8]. It has been stated that music has impacts in decreasing in sympathetic nervous control and eventually a reduction in heart rate and respiration rates, metabolism, oxygen consumption and muscle tension [13]. In [3] it has been stated that:

'Cerebral blood flow changes were measured in response to subject-selected music that elicited the highly pleasurable experience. As intensity of chills increased, cerebral blood flow increases and decreases were observed in brain regions thought to be involved in reward/motivation, emotion, and arousal, including ventral striatum, midbrain, amygdala, orbitofrontal cortex, and ventral medial prefrontal cortex.' [3], p. 11818.

In [6] it is mentioned;

'the Amygdala, hippocampus, fusiform gyrus, striatum, and thalamus are all implicated in emotional reactivity, whereas the OFC, vlPFC, dlPFC, and anterior insula are implicated in effortful regulation of emotion' [6], p. 2.

In [22] it has been shown that during music therapy, clients by using music experiences like free improvisation, singing, listening to, discussing and moving to achieve treatments goals that making better their affective behaviors and states. More on psychological and neuroscientific principles will be explained in Table 1.

3 The Adaptive Temporal-Causal Network Model

First the Network-Oriented Modelling approach used to model this process is briefly explained. As discussed in detail in [12, Chap. 2] this approach is based on temporal-causal network models which can be represented at two levels: by a conceptual representation and by a numerical representation. A conceptual representation of a temporal-causal network model in the first place involves representing in a declarative

Table 1. Explanation of the states in the model

X_1	ws_{ee}	World (body) state of extreme emotion *ee*	X_{17}	$\mathrm{ss}_{singing1}$	Sensor state of sad singing (hearing)
X_2	ss_{ee}	Sensor state of extreme emotion *ee*	X_{18}	$\mathrm{ss}_{singing2}$	Sensor state of happy singing (hearing)
X_3	ws_c	World state for context *c*	X_{19}	$\mathrm{srs}_{singing1}$	Sensory representation of sad singing
X_4	ss_c	Sensor state for *c* (perceiving *c*)	X_{20}	$\mathrm{srs}_{singing2}$	Sensory representation of happy singing
X_5	srs_{ee}	Sensory representation state of extreme emotion *ee*	X_{21}	srs_{m1}	Sensory representation of sad music
X_6	srs_c	Sensory representation state of context *c*	X_{22}	srs_{e1}	Sensory representation state of emotion of sad music
X_7	fs_{ee}	Feeling state for extreme emotion *ee*	X_{23}	srs_{m2}	Sensory representation of happy music
X_8	ps_{ee}	Preparation state for extreme emotion *ee*	X_{24}	srs_{e2}	Sensory representation state of emotion of sad music
X_9	es_{ee}	Execution state (bodily expression) of extreme emotion *ee*	X_{25}	bs_n	Negative belief
X_{10}	srs_b	Sensory representation of body state *b*	X_{26}	bs_p	Positive belief
X_{11}	goal_b	Goal (Relax *b* by music therapy)	X_{27}	ps_{sing1}	Preparation state for singing sad music
X_{12}	ps_b	Preparation state of body state *b*	X_{28}	ps_{sing2}	Preparation state for singing happy music
X_{13}	ws_{m1}	World state of playing sad music m_1	X_{29}	ps_{e1}	Preparation state for emotion of sad music
X_{14}	ws_{m2}	World state of playing happy music m_2	X_{30}	ps_{e2}	Preparation state for emotion of happy music
X_{15}	ss_{m1}	Sensor state of sad music (hearing)	X_{31}	$\mathrm{es}_{singing1}$	Execution state of sad singing
X_{16}	ss_{m2}	Sensor state of happy music (hearing)	X_{32}	$\mathrm{es}_{singing2}$	Execution state of happy singing

manner states and connections between them that represent (causal) impacts of states on each other, as assumed to hold for the application domain addressed. The states are assumed to have (activation) levels that vary over time. In reality, not all causal relations are equally strong, so some notion of *strength of a connection* is used. Furthermore, when more than one causal relation affects a state, some way to *aggregate multiple causal impacts* on a state is used. Moreover, a notion of *speed of change* of a state is used for timing of the processes. These three notions form the defining part of a conceptual representation of a temporal-causal network model:

- **Strength of a connection $\boldsymbol{\omega}_{X,Y}$.** Each connection from a state X to a state Y has a *connection weight value* $\boldsymbol{\omega}_{X,Y}$ representing the strength of the connection, often between 0 and 1, but sometimes also below 0 (negative effect) or above 1.
- **Combining multiple impacts on a state $\mathbf{c}_Y(..)$.** For each state (a reference to) a *combination function* $\mathbf{c}_Y(..)$ is chosen to combine the causal impacts of other states on state Y.
- **Speed of change of a state $\boldsymbol{\eta}_Y$.** For each state Y a *speed factor* $\boldsymbol{\eta}_Y$ is used to represent how fast a state is changing upon causal impact.

Combination functions can have different forms, as there are many different approaches possible to address the issue of combining multiple impacts. Therefore, the Network-Oriented Modelling approach based on temporal-causal networks incorporates for each state, as a kind of label or parameter, a way to specify how multiple causal impacts on this state are aggregated by some combination function. For this aggregation a number of standard combination functions are available as options and a number of desirable properties of such combination functions have been identified; see [12, Chap. 2, Sects. 2.6 and 2.7]. In Fig. 1 the conceptual representation of the temporal-causal network model is depicted. A brief explanation of the states used is shown in Table 1, and their relation to domain literature is indicated in Table 2.

Next, the elements of the conceptual representation shown in Fig. 1 are explained in some more detail. The states ws_c, ws_{ee}, and ws_{m1}, ws_{m2} stand for world states for context c, body state of extreme emotion ee and world state of playing sad and happy music, respectively.

The states ss_c and ss_{ee} are the sensor states of the context c and of body state of extreme emotion ee. The states srs_c and srs_{ee} are the sensory representation states of the context c and the body state for the extreme emotion, respectively. The state srs_c is a trigger affecting the activation level of the preparation state ps_{ee} which is the preparation state for the extreme emotional response ee, and fs_{ee} shows the feeling state associated to this extreme emotion. The state es_{ee} represents the execution state of an extreme emotion (expression in body state). The states srs_b denotes sensory representation of the relaxed body state b. The state goal_b shows the goal for the music therapy to raise body state b (relaxation). The state ps_b is the preparation state of body state b. The states $\left(\mathrm{ss}_{singing1}, \mathrm{ss}_{singing2}\right)$, $(\mathrm{srs}_{m1}, \mathrm{srs}_{m2})$ are the sensor states of singing by the individual and sensor states of music itself for sad and happy music, respectively.

The sensory representation states $(\mathrm{srs}_{m1}, \mathrm{srs}_{m2})$, $\left(\mathrm{srs}_{singing1}, \mathrm{srs}_{singing2}\right)$ are the sensory representation states of music and singing for sad and happy music, respectively. Two belief states bs_n and bs_p are considered here as part of (re)appraisal for the singing. The state bs_p denotes a positive belief and bs_n a negative belief. The preparation states $\mathrm{ps}_{sing1}, \mathrm{ps}_{sing2}$ denote preparation states of singing of sad and happy music, respectively. The states $\left(\mathrm{es}_{singing1}, \mathrm{es}_{singing2}\right)$ denote the execution states of sadly and happily singing.

The connection weights ω_i shown in Fig. 1 are as follows. The sensor states ss_{ee}, ss_{cc} have connections entering from ws_{ee} and ws_c with weights ω_1, ω_2, respectively. The world state of an extreme emotion ws_{ee} has an arriving connection from es_{ee} as a body-loop with weight ω_{11}. The sensory representation state of an extreme emotion srs_{ee} has three arriving connections with weights ω_3, ω_8, ω_{14} from states called sensor

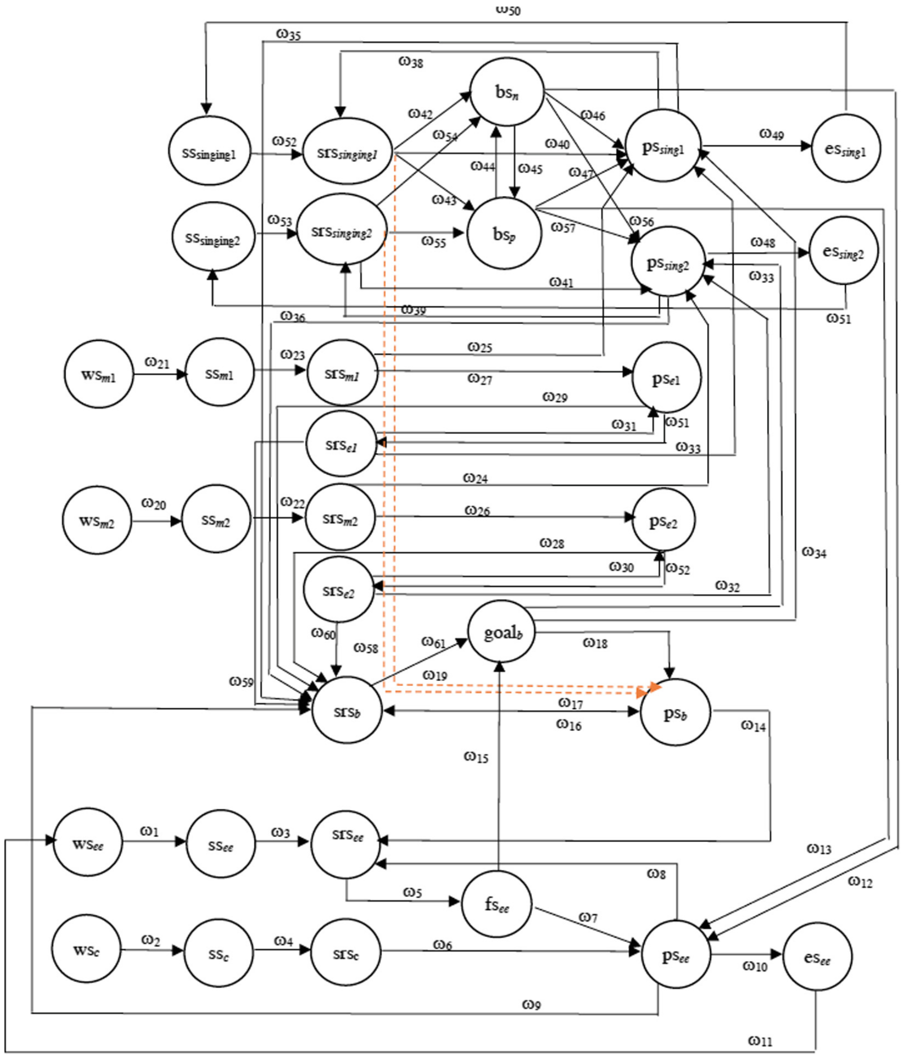

Fig. 1. Conceptual representation of the adaptive temporal-causal network model

state ss_{ee} of an extreme emotion, preparation state ps_{ee} of an extreme emotion, and preparation state ps_b of the relaxed body state b, respectively. The weight ω_5 is the incoming connection weight for the feeling state fs_{ee} from sensory representation state of an extreme emotion. The preparation state ps_{ee} of an extreme emotion has four entering connection weights ω_6, ω_7, ω_{12}, ω_{13} from states srs_c, fs_{ee}, negative belief (bs_n) and positive belief (bs_p), respectively. The incoming connection weight from ps_{ee} of the execution state es_{ee} of an extreme emotion is ω_{10}. The sensory representation state srs_b has six incoming connection weights from execution state of an extreme emotion ps_{ee} (suppression), preparation state of body state of the goal ps_b, preparation state of

Table 2. States and their relations to domain literature

States	Principles	Quotation, references
ws_{ee}	External stressor	External stress-inducing event [12]; 'Cortisol is a hormonal response to acute stress and has been measured to be higher before competition than at resting conditions.' [29], p. 71
ss_{ee}	Sensor state for perception of the stressor	'Emotions give rise to affective experiences such as feelings of happiness, sadness, pleasure, and displeasure; activate widespread physiological adjustments to the evoking conditions; and lead to expressive behaviors that are often, but not always, goal directed and adaptive.' [16], p. 62 'Human states can refer, for example, to states of body parts to see (Eyes), hear (ears) and fee (skin).' [5, 12] p. 52
srs_{ee}	Sensory and feeling representation of stressful event	'The dACC was activated during the observe condition. The dACC is associated with attention and the ability to accurately detect emotional signals.' [19], p. 18
$goal_{b1}$	Executive function and manage goal	'Appropriate use of song material promotes the achievement of therapeutic goals.' [2], p. 10
ss_{m1} ss_{m2}	Sensor state for perception of sad and happy music (hearing)	'Music therapy in the care of cancer patients and their families aims to promote comfort, develop meaningful communication, and resolve issues. The music therapist aims to soothe and energize, stimulate the expression of thoughts and feelings, help integrate families and persons into their social environments, provide sensory stimulation, and diminish pain.' [2], p. 6
$ss_{m1}\,ss_{m2}$	Sensory representation of sad & happy music	'Through songs, they can communicate their problems, their past or present unsatisfied needs or desires, their happiness, their loneliness.' [2], p. 9
ps_{e1} ps_{e2}	Preparation state of state of emotion of sad & happy music (Ventral striatum, ventral medial prefrontal cortex, Regional Cerebral blood flow (rCBF))	'Cerebral blood flow changes were measured in response to subject-selected music that elicited the highly pleasurable experience. As intensity of

(*continued*)

Table 2. (*continued*)

States	Principles	Quotation, references
		chills increased, cerebral blood flow increases and decreases were observed in brain regions thought to be involved in reward/motivation, **emotion**, and arousal, including ventral striatum, midbrain, amygdala, orbitofrontal cortex, and ventral medial prefrontal cortex.' [3], p. 11818
srs_{e1} srs_{e2}	Sensory representation of emotion of sad and happy music	'Music offers a comfortable, nonthreatening milieu which is an important aspect for the mood of the patient during therapy sessions.' [3], p. 11820
ps_{sing1} ps_{sing2}	Preparation state of singing	'The sound of the human voice provides intimate contact between the source and the listener, for the human voice is an individual's most intimate means of self-expression. The voice is the instrument through which a human communicates sounds and by which infants form the association between bodily contact and sound.' [2], p. 7 'The music therapist can use the verbal messages within the songs to promote enhanced exploration of inner thoughts and feelings.' [2], p. 6
es_{sing1} es_{sing2}	Execution state of singing (sad and happy)	'Songs are unique in that, by their nature, they need medium for the words to be expressed. This medium is most often the human voice'. [2], p. 7
ps_b	Preparation state for body states $b1$ and $b2$	'A complex mosaic of interconnected Frontal lobe areas that lie rostral to the Primary motor cortex also contributes importantly to motor functions. The medial premotor cortex, like the lateral area, mediates the selection of movements.' [23], p. 23
srs_b	Sensory representation and feeling of body states (Bilateral anterior temporal lobe)	'Bilateral anterior temporal lobe Task domain: emotion and affect. Core affect generation: engaging vicermotor control of the body to create core affective feelings of pleasure or displeasure with some degree of arousal' [21], p. 2112

singing ps_{sing1}, ps_{sing2} (sad and happy), sensory representation state of emotion of sad and happy music srs_{e1}, srs_{e2} (The feeling of singing may be positive and as such have a positive impact on a positive belief and a negative impact on a negative belief).

Two types of music are addressed: happy music makes individual sing a happy song and sad music makes her sing a sad song. The effect on the singing from the positive and the negative beliefs has connection weights named ω_{46}, ω_{47} (for sad singing) ω_{56}, ω_{57} (for happy singing) respectively. The state $goal_b$ has one incoming connection ω_{15} from srs_{ee}. The preparations state ps_b of the body state b has four incoming connection weights $(\omega_{17}, \omega_{18}, \omega_{19}, \omega_{55})$ from $\left(srs_b, goal_b, ss_{singing1}, ss_{singing2}\right)$, respectively. Note that dotted lines in the model shows the Hebbian learning connections $(\omega_{19}, \omega_{55})$.

The states $ss_{singing1}, ss_{singing2}$ both have an entering connection weights ω_{50} and ω_{51} from execution states of es_{sing1} and es_{sing2}. The sensor state ss_{m1} and ss_{m2} both have an arriving connection weight from world state of music ws_{m1} and ws_{m2} named ω_{20} and ω_{21}. The preparation state of singing has two incoming connection weights are $(\omega_{26}\ \omega_{27})$, $(\omega_{30}\ \omega_{31})$ from ss_{m1} and ss_{m2}, respectively. The sensory representation state of emotion of sad and happy music has three incoming connection weights from sensor state of singing $ss_{singing}$, sensory representation of music srs_m and preparation state of singing $ps_{singing}$ named ω_{25}, ω_{24}, and ω_{35} respectively. The negative belief state bs_n has three connection weights from $ss_{singing1}$, $ss_{singing2}$ and for being exclusive from positive belief bs_p, ω_{42}, ω_{54} and ω_{44} respectively and similar for bs_n as ω_{43}, ω_{55} and ω_{43}. The preparation state of singing, ps_{sing1} and ps_{sing2} have six incoming connection weights from the $goal_b$, the negative belief, the positive belief, $srs_{singing1}$, and srs_{e1} with ω_{34}, ω_{46}, ω_{40}, ω_{25}, ω_{34} and ω_{47} and vice versa for ω_{56}, ω_{57}, ω_{36}, ω_{33}, ω_{32} and ω_{24}. The execution states of singing, $es_{singing1}$, $es_{singing2}$ both have an incoming connection weight ω_{49}, ω_{48} from preparation states ps_{sing1}, ps_{sing2}, respectively.

This conceptual representation was transformed into a numerical representation as follows [12, Chap. 2]:

- at each time point t each state Y in the model has a real number value in the interval [0, 1], denoted by $Y(t)$
- at each time point t each state X connected to state Y has an impact on Y defined as $\mathbf{impact}_{X,Y}(t) = \omega_{X,Y}\, X(t)$ where $\omega_{X,Y}$ is the weight of the connection from X to Y
- The *aggregated impact* of multiple states X_i on Y at t is determined using a *combination function* $\mathbf{c}_Y(..)$:

$$\begin{aligned}\mathbf{aggimpact}_Y(t) &= \mathbf{c}_Y\left(\mathbf{impact}_X 1_{,Y}(t), \ldots, \mathbf{impact}_X \mathrm{k}_{,Y}(t)\right) \\ &= \mathbf{c}_Y\left(\omega_X 1_{,Y} X_1(t), \ldots, \omega_X k_{,Y} X_K(t)\right)\end{aligned}$$

  where X_i are the states with connections to state Y
- The effect of $\mathbf{aggimpact}_Y(t)$ on Y is exerted over time gradually, depending on speed factor η_Y:

$$Y(t+\Delta t) = Y(t) + \eta_Y[\mathbf{aggimpact}_Y(t) - Y(t)]\Delta \mathrm{t}$$
$$\text{or} \qquad \mathbf{d}Y(t)/\mathbf{d}t = \eta_Y[\mathbf{aggimpactY(t)} - Y(t)]$$

- Thus, the following *difference* and *differential equation* for Y are obtained:

$$Y(t+\Delta t) \;=\; Y(t) + \eta_Y\left[\mathbf{c}_Y\left(\omega_X 1_{,Y} X_1(t), \ldots, \omega_X k_{,Y} X_k(t)\right)\right]\Delta t$$
$$\mathbf{d}Y(t)/\mathbf{d}t = \eta_Y\left[\mathbf{c}_Y\left(\omega_X 1_{,Y} X_1(t), \ldots, \omega_X k_{,Y} X_k(t)\right)\right] - Y(t)$$

For states the following combination functions $\mathbf{c}_Y(\ldots)$ were used, the identity function **id(.)** for states with impact from only one other state, and for states with multiple impacts the scaled sum function $\mathbf{ssum}_\lambda(\ldots)$ with scaling factor λ, and the advanced logistic sum function $\mathbf{alogistic}_{\sigma,\tau}(\ldots)$ with steepness σ and threshold τ.

$$\mathbf{id}(V) = V$$
$$\mathbf{ssum}_\lambda(V_1, \ldots, V_k) = (V_1, \ldots, V_k)/\lambda$$
$$\mathbf{alogistic}_{\sigma,\tau}(V_1, \ldots, V_k) = \left[\left(1/\left(1 + \mathrm{e}^{-\sigma(V_1 + \ldots + V_{k-\tau})}\right)\right) - 1/(1 + \mathrm{e}^{\sigma}\tau)\right](1 + \mathrm{e}^{-\sigma}\tau)$$

Here first the general Hebbian Learning is explained which is applied to ω_{35} and ω_{36} for $(X_{19}, X_{15}$ and $X_{20}, X_{16})$. In a general example model considered it is assumed that the strength ω of such a connection between states X_1 and X_2 is adapted using the following Hebbian Learning rule, taking into account a maximal connection strength 1, a learning rate $\eta > 0$ and a persistence factor $\mu \geq 0$, and activation levels $X_1(t)$ and $X_2(t)$ (between 0 and 1) of the two states involved [10]. The first expression is in differential equation format, the second one in difference equation format:

$$\mathrm{d}\omega(t)/\mathrm{d}t = \eta[X_1(t)\,X_2(t)\;(1 - \omega(t) - (1 - \mu)\omega(t)]$$
$$\omega(t+\Delta t) = \omega(t) + \eta[X_1(t)\,X_2(t)(1 - \omega(t)) - (1 - \mu)\omega(t)]\Delta t$$

4 Example Simulation

An example simulation of this process is shown in Figs. 2 and 3. Table 3 shows the connection weights used, where the values for the Hebbian learning connections are initial values as these weights are adapted over time. The time step was $\Delta t = 1$. The scaling factors λ_i for the states with more than one incoming connection are also depicted in Table 3. In the scenario, the music is used as a therapy to decrease the level of the extreme emotion of the stressed individual. At a first step, an external world state of the stressful context c (denoted by X_1) affects the internal world state of the individual state with an extreme emotion (denoted by X_3). The stressed person senses the extreme emotion (denoted by X_2); by this the sensory representation of an extreme emotion of an individual comes to have a role (denoted by X_5), also the music comes in (The upper part of the model as the music starting by X_{17}, X_{18}). In this scenario, two types of music are considered as a therapy called sad and happy music. For simplicity, here we just simulate only one type of music, happy music and put the value of sad music to zero and without any effect on the stressed person. There is a main goal which is considered as the goal to achieve relaxation by singing with the music. The sensory representation of music has an influence on preparation state of the body state *b* (denoted by X_{27} and X_{12}) and decreases the preparation state of the extreme emotion to affect the sensory representation of the extreme emotion of the individual (denoted by X_5).

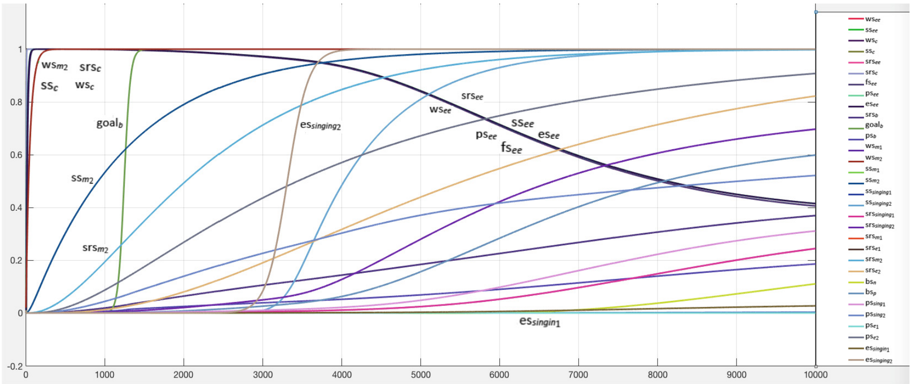

Fig. 2. Simulation results of the music therapy

There are two beliefs (denoted by X_{25} and X_{26}: positive and negative belief, respectively), and there are two sensory representations of emotion which are also considered to have impacts on sensory representation of body state, X_{10} as a sensory representation state of body state *b*. When the music therapy starts the stressed individual senses and hears the music (denoted by X_{15} and X_{16}). The goal gets a role from time around 1200 on. After giving some time to the stressed individual to hear and sense the music the preparation and sensory representation of emotion starts to have a role and after internally being emotional she starts singing from time around 2000 as an as-if loop from preparation state of singing (X_{22} and X_{24} as sensory representation states of emotion) so she makes it stronger and prepared to perform singing (X_{27} and X_{28}) to be more relaxed. As can be seen from the simulation of the sad singing and music, this has no effect on reducing the stress level in contrast to the reducing effect of the happy music and singing. in that case the reduction of the stress level continues until the time around 10000 to become in the equilibrium level from 1 (high-level of stress) to just 0.4 (low-level of stress). Mirroring links are considered between the sensory representation of body state and the preparation state of the body state (denoted by X_{10} and X_{12}).

As it can be seen from Fig. 3, the Hebbian learning connections which have been used from $\mathrm{srs}_{singing1}$, $\mathrm{srs}_{singing2}$ to ps_b show increase from time 4000. The parameter setting for both Hebbian Learning connections are as follows; for both connections the speed factors η are equal to 0.5, and the persistence factors μ are equal to 0.97.

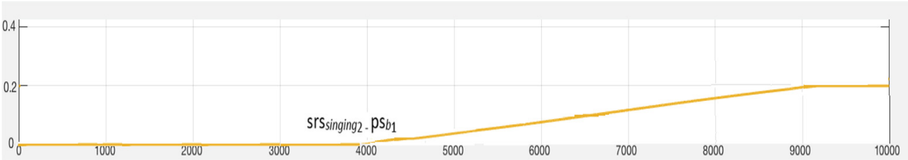

Fig. 3. Simulation results for Hebbian learning connections

Table 3. Connection weights for the example simulation

Connection weight	ω_1	ω_2	ω_3	ω_4	ω_5	ω_6	ω_7	ω_8
Value	1	1	1	1	1	1	1	1
Connection Weight	ω_9	ω_{10}	ω_{11}	ω_{12}	ω_{13}	ω_{14}	ω_{15}	ω_{16}
Value	–0.001	1	1	0.2	-1	-0.1	1	1
Connection Weight	ω_{17}	ω_{18}	ω_{19}	ω_{20}	ω_{21}	ω_{22}	ω_{23}	ω_{24}
Value	1	0.01	0.01	1	1	1	1	1
Connection Weight	ω_{25}	ω_{26}	ω_{27}	ω_{28}	ω_{29}	ω_{30}	ω_{31}	ω_{32}
Value	1	1	1	1	0.1	0.1	1	1
Connection Weight	ω_{33}	ω_{34}	ω_{35}	ω_{36}	ω_{37}	ω_{38}	ω_{39}	ω_{40}
Value	1	1	1	1	1	1	1	1
Connection Weight	ω_{41}	ω_{42}	ω_{43}	ω_{44}	ω_{45}	ω_{46}	ω_{47}	ω_{48}
Value	1	1	–0.2	–0.15	–0.15	–0.9	–0.9	1
Connection Weight	ω_{49}	ω_{50}	ω_{51}	ω_{52}	ω_{53}	ω_{54}	ω_{55}	ω_{56}
Value	1	1	1	1	1	–0.01	1	1
Connection Weight	ω_{57}	ω_{58}	ω_{59}	ω_{60}	ω_{61}			
Value	–0.9	0.01	1	1	–0.9			

state	X_5	X_8	X_{10}	X_{12}	X_{19}	X_{20}	X_{25}
λ_i	2	2	3	3	1.1	2	1
state	X_{26}	X_{27}	X_{28}	X_{29}	X_{30}		
λ_i	1	2.21	4.01	1	2		

5 Discussion

In this paper an adaptive cognitive temporal-causal network model of a mindfulness therapy based on music was presented by helping Hebbian learning to decrease the level of stress of individual with extreme stress. As far as the authors know there do not exist computational models for such a therapy. Due to Hebbian learning the model is adaptive by which the effect becomes stronger over time.

A variety of simulations were executed one of which was presented in the paper. Findings from Neuroscience were taken into account in the design of the adaptive model. This literature reports experiments and measurements of music therapy for emotion-induced conditions as addressed from a computational perspective in the current paper.

This model can be used as the basis of a virtual agent model to get insight in such processes and to consider certain support or treatment of individuals and prevent some stress-related disorders that otherwise might develop. In further research, control states in the brain can be added for more antecedent-focused and response-focused emotion regulation strategies.

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